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AD-A162 001

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER M4/86	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EFFECT OF HEAT AND CHEMICAL PROTECTIVE CLOTHING ON COGNITIVE PERFORMANCE.		5. TYPE OF REPORT & PERIOD COVERED final 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Bernard J. Fine & John L. Kobrick		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US ARMY Research Institute of Environmental Medicine, Natick, MA 01760		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 3M161102BS10 64882101011
11. CONTROLLING OFFICE NAME AND ADDRESS Same as 9.		12. REPORT DATE Nov 85 13. NUMBER OF PAGES 24
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

DTIC ELECTE DEC 0 4 1985 S D

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18. SUPPLEMENTARY NOTES

To be published in Aviation, Space & Environmental Medicine/

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Heat, Chemical protective clothing, cognitive performance, climatic stress, military performance, group productivity

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study examined the effects of heat on the sustained cognitive performance of sedentary soldiers clad in chemical protective clothing. Twenty males trained for 2 weeks on selected military tasks. Then, they performed the tasks for 7-hour periods on 4 successive days in hot (32.8C., 61%rh) and normal (21.1C 35%rh) conditions, with and without protective clothing. After 4-5 hours in the heat wearing protective clothing, the cognitive performance of the group began to deteriorate markedly. By the end of 7 hrs. of heat, increases in % group error on investigator-paced tasks ranged from 17% to 23% over control conditions.

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Effect of Heat and Chemical Protective Clothing on Cognitive Performance

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Running Head: Heat and Cognitive Performance

Abstract

This study examined the effects of heat on the sustained cognitive performance of sedentary soldiers clad in chemical protective clothing.

Twenty males trained for two weeks on selected military tasks. Then, they performed the tasks for seven-hour periods on four successive days in hot (32.8 °C., 61%rh) and "normal" (21.1 °C., 35%rh) conditions, with and without protective clothing.

After four to five hours in the heat wearing protective clothing, the cognitive performance of the group began to deteriorate markedly. By the end of seven hours of heat exposure, increases in percent group error on investigator-paced tasks ranged from 17% to 23% over control conditions. Virtually all of the decrements were due to increases in errors of omission. The productivity of the group on a self-paced task (map plotting) diminished by approximately 40% from control conditions after six hours in the heat in protective clothing; accuracy of plotting was not markedly affected.

Climatic stress; military performance; group productivity

Effect of Heat and Chemical Protective Clothing on Cognitive Performance

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The purpose of this study was to determine the effects of moderate heat on the sustained performance of sedentary soldiers wearing chemical protective clothing.

The current standard clothing ensemble for defense against nuclear, biological and chemical (NBC) agents is designed to provide effective physical protection for the soldier. However, its relative impermeability results in hot and humid conditions developing within the ensemble. These conditions can reach hazardous or incapacitating levels, particularly when the system is worn completely closed in a hot or hot-wet environment during strenuous physical work.

Previous research (8,12) has focussed primarily on physiological reactions and/or physical work limits of individuals wearing the ensemble, rather than on performance capabilities. A review by Carr et al. (2) summarized the effects of NBC clothing on performance, but primarily in terms of military units, rather than individual soldiers. Very little research has been done to study the limitations imposed by the NBC ensemble on individual aspects of psychomotor, visual, perceptual, auditory or cognitive behavior. There has been no research done on the impact of extreme climates on soldiers in NBC protective clothing who are working on jobs not requiring strenuous physical activity.

Exposure to heat has been shown to affect performance markedly in sedentary types of work, particularly during sustained operations (6 and unpublished research by the authors). Many such work regimens are extremely

stressful in and of themselves, demanding prolonged concentration and great accuracy. Artillery fire direction centers (FDC's), radar units, air traffic control facilities and command and control activities are of particular relevance.

The few studies that have investigated relatively sedentary soldiers performing in protective clothing (e.g.9,10) are lacking in important scientific and methodological considerations, and have not been concerned with sustained performance.

Kobrick and Fine (11), in a review of research on the effects of heat on human performance, cited three major shortcomings: (1) reliance on unrealistic tasks for assessing performance, (2) inadequate training on the tasks and (3) insufficient duration of exposure to the heat.

In view of these three considerations, it seems appropriate that evaluation of the NBC ensemble be performed in the context of a realistic military scenario. That is. the wearers should be engaged in performance of tasks that would be performed routinely by at least some troops during an NBC attack; the tasks should be overlearned, as they would be among trained troops; and the exposure to the heat should be at least as long as the period of time for which the protective clothing is considered to provide effective physical protection.

In order to satisfy these criteria, a set of performance tasks and a study design used successfully in previous research (6 and unpublished research by the authors) was adapted and modified for use in this study. The tasks included certain aspects of those performed by individual members of FDC teams, by forward observers and by Army communications personnel. These kinds of tasks could be among the most important to be performed during NBC attacks, since effective artillery operations and efficient and accurate communications

would be essential for defense of troops immobilized by NBC actions.

Method

Subjects

Twenty-three male soldier volunteers, ages 19-27 (median=21), were studied. All were screened by a medical officer. Only persons who could read without glasses were acceptable. All personnel were briefed on the purposes and design of the study and its potential hazards and signed voluntary consent forms. (Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.)

Tasks

The major dependent variables were:

(1) Computation of "Site:" - "Site" is a correction factor used by FDC's to adjust for the asymmetrical trajectory of an artillery round and is computed using an artillery slide rule. The data necessary to compute Site was tape-recorded prior to the study. During the study, it was transmitted to the subjects over headsets in a format similar to that used to transmit artillery fire missions. Subjects recorded the information on a standard form, performed addition and/or subtraction on aspects of the information, entered data into and read answers from the slide rule and recorded the answers, with appropriate algebraic signs.

(2) Receiving and decoding map grid coordinates using a standard Army codewheel: - Pre-recorded, coded map grid coordinates were transmitted as simulated radio messages to the subjects through headsets. Each subject recorded the alpha-coded grid coordinates on a standard form, selected the correct one of three codewheels, transcribed the coded material into a numeric format and recorded the transcription on the form.

(3) Receiving and decoding messages: - Pre-recorded, coded messages

varying in length from five to eight words were transmitted to the subjects as radio messages via headsets. The subjects recorded each coded message on an appropriate form, decoded it by referring to a simulated Army codebook and recorded the transcription on the form.

(4) Plotting targets on maps and determining range and deflection: - Each subject was issued a map with three artillery battery positions pre-plotted along with deflection reference points. They were also given identical lists of targets (grid coordinates) to plot, simulating pre-planned fire missions. Each subject plotted each target, using an artillery plotting scale, marked the location of the target by inserting a map pin at the appropriate point, drew a circle around the target and numbered it. The range and deflection of the target from a designated battery then was measured using an artillery protractor. Answers were recorded on a form and included the time at which the calculations for each target had been completed, thus enabling assessment of number of plots per unit of time. Further complication was introduced by having a number of "No Fire Zones," delineated by sets of grid coordinates, listed on each subject's report form. Subjects had to show their awareness of the zones by indicating on the form whether or not they should fire at each target they had plotted. The "No Fire Zones" were changed after every ten targets to prevent their memorization and to increase the need for alertness by the subjects.

The Site calculation, codewheel and codebook tasks were paced by the rate and frequency of transmission of the radio messages ("investigator-paced") and could not be controlled by the subjects. The map plotting task was either investigator-paced or "self-paced" (each subject having control of his own work rate), depending upon when it was performed.

The subjects did not know which of the three radio-transmitted tasks they

would be required to perform until a specific message arrived. The messages were designed to mimic actual military radio transmissions, including a variety of voices and transient background noise.

In addition to the above tasks, two others were included as dependent measures: (1) a visual field surveillance task and (2) an auditory perception task. The results of these tasks will be reported elsewhere. A number of other measurements also were obtained including the Maudsley Personality Inventory (5), The Gottschaldt Hidden Shapes Test (3), selected sub-tests from the Cattell 18-Objective-Analytic Test Battery (3), and selected vision tests, including acuity, depth perception, color blindness, phoria, contrast sensitivity and color discrimination ability. Results related to these tests will appear elsewhere.

Design and Procedure

The subjects were tested in six-man groups, each group completing its assignment before the next was tested. Each group underwent two weeks of intensive training followed by a third "experimental" week in a climatic chamber to evaluate performance in the heat while wearing US Army NBC protective clothing. The clothing ensemble is known as the Mission Oriented Protective Posture (MOPP) system. It provides four levels of increasing chemical protection ranging from slight (MOPP-I) to complete encapsulation (MOPP IV). The latter configuration of the system was worn in this study and consisted of the suit, worn completely closed, along with the boots, gloves, mask and hood.

The subjects trained in a classroom setting, six to seven hours per day, for two weeks, exclusive of week-ends. Training in the codewheel, codebook and Site computation tasks began with a simple written format, and progressed through oral presentations by the instructor, slow radio transmissions with

the instructor's voice, slow radio transmissions with a variety of voices and, finally, at speed, with a variety of voices. During training, subjects practiced several hundred radio messages with immediate feedback of correctness of responses and discussion of errors. Map plotting was practiced for hundreds of trials over the two-week period, also with immediate feedback as to the correctness of responses. Emphasis was placed first on accuracy, then on speed of performance. All subjects received constant individual attention.

Toward the end of the first week, the subjects were trained in proper procedures for wearing the NBC clothing and practiced their tasks briefly while wearing single but critical components of the gear, e.g., gloves only or mask only. During the second week, they performed the tasks daily with and without the NBC suit at the appropriate temperatures (see below). By the beginning of the third week, all subjects had performed all tasks in MOPP IV for about eight hours, spread over five days.

The "experimental" week proceeded as follows:

Monday- Two one-hour "refresher" runs to bring subjects up to pre- weekend performance levels on the various tasks (21.1 °C., 35%rh);

Tuesday- "BDU-Control-1:" seven hours at 21.1 °C., 35%rh, Army battle dress uniform (BDU);

Wednesday- "MOPP-Control:" seven hours at 12.8 °C., 35%rh, MOPP IV worn over BDU;

Thursday- "BDU-Control-2:" same as Tuesday;

Friday- "MOPP-Heat-Stress:" seven hours at 32.8 °C., 61%rh, MOPP IV worn over BDU.

The 12.8 °C. ambient temperature on the MOPP-Control Day was used to equate that condition with the 21.1 °C. BDU-Control conditions. The two

conditions were calculated as being equivalent for a seven-hour exposure by procedures developed at this Institute by J.R. Breckenridge. This "matching" of ambient temperatures was necessary to insure that the MOPP-Control condition reflected the effect of wearing the protective garment only and was not an additional effect of heat.

Ideally, the design of this study should have included a heat "control" condition in which subjects worked in BDU at 32.8 °C., 65%rh (Effective Temperature= 28 °C.). However, because previous research (Fine and Kobrick, unpublished) showed that a more stressful environment (40.6 °C., 40%rh; Effective Temperature= 31.1 °C.) had no effect on men in BDU performing the same tasks as in this study, and because it was necessary to limit the experiment to one week, a BDU Heat-Control condition was not included.

The tasks were presented as one-hour blocks of messages. Twenty-five messages were transmitted each hour. Of these, five were irrelevant (messages with addresses to which the subjects had been trained not to respond), six were codebook tasks, six were codewheel tasks and eight were computations of Site.

The intervals between messages ranged from approximately 30 seconds to over two minutes according to a pre-established random pattern. There were no duplicate messages throughout the entire experiment.

The sequence in which the 25 messages were transmitted, that is, whether a message was a fire mission (Site computation), codewheel, codebook, or irrelevant, was pre-established according to a random procedure. However, each subject started the sequence at a different message. Subject #1 received a sequence of messages from #1 to #25. Subject #2 received identical messages, except that his series started with message #2 and ended with message #1. Subject #3 started with message #3 and ended with message #2 and so on through

the six subjects. This pattern was kept constant for each subject for all hours in which he received messages. Since the messages and the intervals between them varied in length, the subjects' work patterns differed from one another. As a result, the subjects readily perceived that they could not depend upon one another for answers or to be alerted when a message began.

Radio messages were presented to the subjects four times on each of the four experimental days, as hours 1,3,5 and 7.

Concurrently with the radio message task, the subjects performed the map task, plotting targets and determining ranges and deflections when not engaged in actual message reception, translation or the computation of Site. Thus, for each of hours 1,3,5, and 7, each subject was continuously engaged in work of a cognitive nature. During those hours, the radio messages were given highest priority. Map work was interrupted immediately upon hearing a radio message, to be resumed only after completing the work required by the message.

During the intervening hours (2,4, and 6), the subjects worked continuously on the map plotting task, but were interrupted briefly for testing, in groups of three, on the auditory perception test and, individually, on the peripheral vision task. During these hours, subjects worked at their own pace on the map task for approximately 35 minutes without being interrupted by radio messages. It should be noted that in each "one-hour" period, actual working time was 50 minutes, with a ten-minute rest period.

During the MOPP-Heat-Stress condition, rectal temperatures were taken at five- minute intervals or more frequently, if necessary. Safety regulations required removal of subjects from the chamber if their rectal temperatures reached 39.5 ~~degrees~~ °C., or as directed by the medical officer or the principal investigator. Each subject had a canteen of water readily available

and was encouraged to drink, particularly during rest periods. Drinking from the canteen while wearing the NBC mask was accomplished via a rubber tube installed as a standard accessory for that purpose. Fresh water was provided every hour and subjects were checked frequently to insure that they all obtained adequate liquid. No lunch was eaten on any of the experimental days. Access to a portable toilet was permitted but only for genuine emergencies. Only three of 20 subjects availed themselves of this opportunity during the entire study.

Results and Discussion

Although the study design called for 24 subjects, 23 actually arrived to participate. Of those, three were disqualified; one was allergic (rash) to the protective clothing, one missed parts of several training sessions because of illness and one went on sick-call on the final (stress) day. Therefore, all data analyses are based on 20 subjects.

The subjects' responses to the radio messages were scored and verified for accuracy against a set of response criteria and error priorities established beforehand. Errors were classified into those of omission and commission. An error of omission consisted of missing part of an incoming message or omitting something from its translation. Errors of commission included incorrect reception of messages and incorrect translations and computations.

On the MOPP-Heat-Stress day, two subjects were removed from the chamber for medical reasons prior to the completion of the exposure. For the time period that they missed, they were scored as having the maximum number of omission errors possible for each of the radio-transmitted tasks and as having plotted no targets. The group averages reported for those tasks include these maximum error scores. This provides a more legitimate assessment of group performance than would the exclusion of that data. This issue has been

discussed previously by Fine and Kobrick (6,p.121).

The data were analyzed by three procedures. First, analyses of variance (ANOVA's) were computed for each of the tasks, using the total error scores of each subject, in order to determine the statistical significance of the effects of experimental conditions, elapsed hours of work and their interaction on task performance. The results of these ANOVA's are presented below in narrative form.

Second, the actual numbers of errors committed by each subject for each of the radio reception tasks were converted to percent of total possible errors for that task. The percentages then were averaged for the group of subjects and are the basis for the graphic presentations used herein.

Third, "internal" comparisons (differences between elapsed hours of work within conditions, or between conditions after a given number of hours of work) were made using the Least Significant Difference Test (1,13), and are discussed below.

The specific results are as follows:

CODEBOOK: The results for the Codebook task are depicted graphically in Figure 1 and represent errors of omission and commission combined.

INSERT FIGURE 1 ABOUT HERE

The ANOVA for the codebook task resulted in a significant main effect for Conditions ($F=11.76; d.f.=3,304; p<.0001$) and a significant interaction between Conditions and Elapsed Hours of Work ($F=4.12; d.f.=9,304; p<.0001$).

No significant differences between the two BDU-Control conditions were evident at any time, nor were there any significant differences between hours of testing within either of these control conditions. This indicates that the subjects had reached a consistent level of performance which did not vary significantly over seven hours.

The NBC suit, by itself (MOPP-Control condition), appeared to cause a decrement in performance of the Codebook task. This effect was not clearcut statistically for the first three hours of exposure, but after five elapsed hours of work the effect became more pronounced; the MOPP-Control condition differed significantly from both BDU controls, as did the MOPP-Heat-Stress condition. After seven elapsed hours of work, two distinctly opposite patterns became evident. Performance in the MOPP-Control condition improved to the level of that in the BDU-Control conditions, whereas the group, when in the MOPP-Heat-Stress condition, showed a statistically significant increase in errors in excess of 30 percent.

It is difficult to account for the initial decrement in performance in the MOPP-Control condition, particularly since the subjects had practiced the task in MOPP IV at that temperature for at least eight hours during the training week preceding the experiment. The results might have been due to apprehension on the part of some subjects about wearing the protective suit for the first time in an experimental situation, or to a direct effect of the 12.8 °C. temperature on manual dexterity. It is significant to note that 12.8 °C. has been shown to be the limiting hand skin temperature for effective motor performance (4,7). A number of subjects did complain about having cold hands and of having difficulty writing. Some even complained of pain. It also is possible that the attendant discomfort could have interfered with subjects' ability to concentrate, resulting in an increase in errors of omission.

Further analysis clearly indicated that the decrements in group performance in both the MOPP-Control and the MOPP-Heat-Stress conditions were due almost entirely to increases in errors of omission rather than errors of commission. This suggests that the decrement in performance observed in the MOPP-Control condition was not due to impaired dexterity, since such an

impairment would be expected to result in an increase in writing errors, i.e., errors of commission. The possible interference of discomfort with the ability to concentrate still remains a viable explanation.

CODEWHEEL: The results of the Codewheel task are graphically shown in Figure 2. The ANOVA yielded a significant main effect for Conditions ($F=14.28$; $d.f.=3,304$; $p<.0001$), and a significant Conditions by Elapsed Hours of Work interaction ($F=4.11$; $d.f.=9,304$, $p<.0001$).

INSERT FIGURE 2 ABOUT HERE

Performance in the BDU-Control conditions showed remarkable consistency and stability over time; at the end of seven hours, the subjects, as a group, were performing at the same high level of competence (5% errors) as they were after the first hour on the task.

The diametrically opposite trends of the two MOPP conditions, which were observed with the codebook task, clearly were evident again. In the MOPP-Control condition, performance was adversely affected initially (significant only after the first and third hours of work), and gradually improved until, after seven hours, it approached the performance levels of the two BDU-Control conditions. The MOPP-Heat-Stress condition showed no adverse effects initially, but dramatic and significant increases in average group error occurred from the third to the fifth and the fifth to the seventh hours. Virtually all of the increase occurred as errors of omission.

COMPUTATION OF SITE: This was the only radio transmitted task in which the messages were presented twice, due to the difficulty of message content. The effect of the message repetition is evident in the lower error rates for this task shown in Figure 3. The ANOVA resulted in significant main effects for Conditions ($F=7.26$; $d.f.=3,304$; $p<.0001$) and for Elapsed Hours of Work ($F=2.83$; $d.f.=3,304$; $p<.05$) and a significant Conditions by Hours interaction ($F=3.00$;

d.f.=9,304;p<.002).

INSERT FIGURE 3 ABOUT HERE

Performances in the two BDU-Control conditions again were highly stable, remarkably similar and quite free of errors. The group, in these control conditions, averaged only 2-3% errors consistently for each of the four hours in which the task was performed.

There was no significant decrement in performance in the MOPP-Control condition at any time. The MOPP-Heat-Stress condition showed significant increases in percent group error from the third to the fifth and from the fifth to the seventh hours, culminating in a performance decrement of approximately 20%. This was found to be due entirely to an increase in errors of omission.

MAP PLOTTING: The results of this task are separated into two categories: performance that was concurrent with radio message reception (hours 1,3,5,7; referred to as "investigator-paced") and performance without that task interference (hours 2,4,6; "self-paced").

NUMBER OF TARGETS PLOTTED, HOURS 1,3,5 AND 7: Figure 4 depicts the average number of targets plotted by the group by Conditions and Elapsed Hours of Work. The ANOVA resulted in a significant main effect for Conditions (F=11.43; d.f.=3,304;p<.0001), and a marginally significant effect for Elapsed Hours of Work (F=2.23;d.f.=3,304;p<.10). There was a consistent tendency for more targets to be plotted in the BDU-Control-2 condition than in the BDU-Control-1 condition, but the difference between the two conditions was significant only for the third hour of exposure.

INSERT FIGURE 4 ABOUT HERE

Of greater importance was the tendency for target plotting productivity to be lower in the MOPP conditions. However, this effect was not consistently

statistically significant; that is, it did not hold when both BDU control groups were compared with both MOPP groups. The effect was much more apparent when the data for hours 2,4,and 6 were considered.

NUMBER OF TARGETS PLOTTED, HOURS 2,4,AND 6: The data for number of targets plotted during hours 2,4,and 6 are shown graphically in Figure 5.

INSERT FIGURE 5 ABOUT HERE

The ANOVA resulted in a very large F value for Conditions ($F=31.43$; d.f.=3,228; $p<.0001$). As in hours 1,3,5 and 7, subjects were more productive in the BDU-Control-2 condition than in the other conditions. Here, however, the effect was significant for each of hours 2,4 and 6. It is difficult to account for this performance other than to surmise that since this control condition followed the first full-day of wearing MOPP IV (MOPP-Control condition), the subjects felt so good without the protective gear that their performance soared.

Insofar as the effects of the NBC suit are concerned, by the fourth hour the group, when in either MOPP condition, had significantly lower productivity than when in either BDU-Control condition. By the end of the sixth hour, however, productivity in the MOPP-Control condition had improved to the same level as the BDU-Control-1 condition, whereas productivity in the MOPP-Heat-Stress condition showed a significant decrease (10.7 targets plotted per hour, compared with 17.6 per hour for MOPP-Control, 19 per hour for BDU-Control-1 and 23 per hour for BDU-Control-2). Again, the stability and magnitude of performance in the BDU-Control conditions should be noted, attesting both to the effective training procedures and the high level of motivation of the subjects.

CONCLUSIONS

The data indicate conclusively that after four to five hours of exposure

in a climatic chamber to a moderately hot environment, the cognitive performance of a group of highly trained soldiers clad in the MOPP IV configuration of NBC protective clothing began to deteriorate markedly. By the end of seven hours of exposure to heat, increases in percent group error ranged from 17% to 23% over control conditions on investigator-paced tasks. Virtually all of this decrement was due to increases in errors of omission. The productivity of the group on a self-paced task (map plotting) diminished by approximately 40% from control conditions after six hours in the heat, but accuracy of plotting did not appear to be markedly affected.

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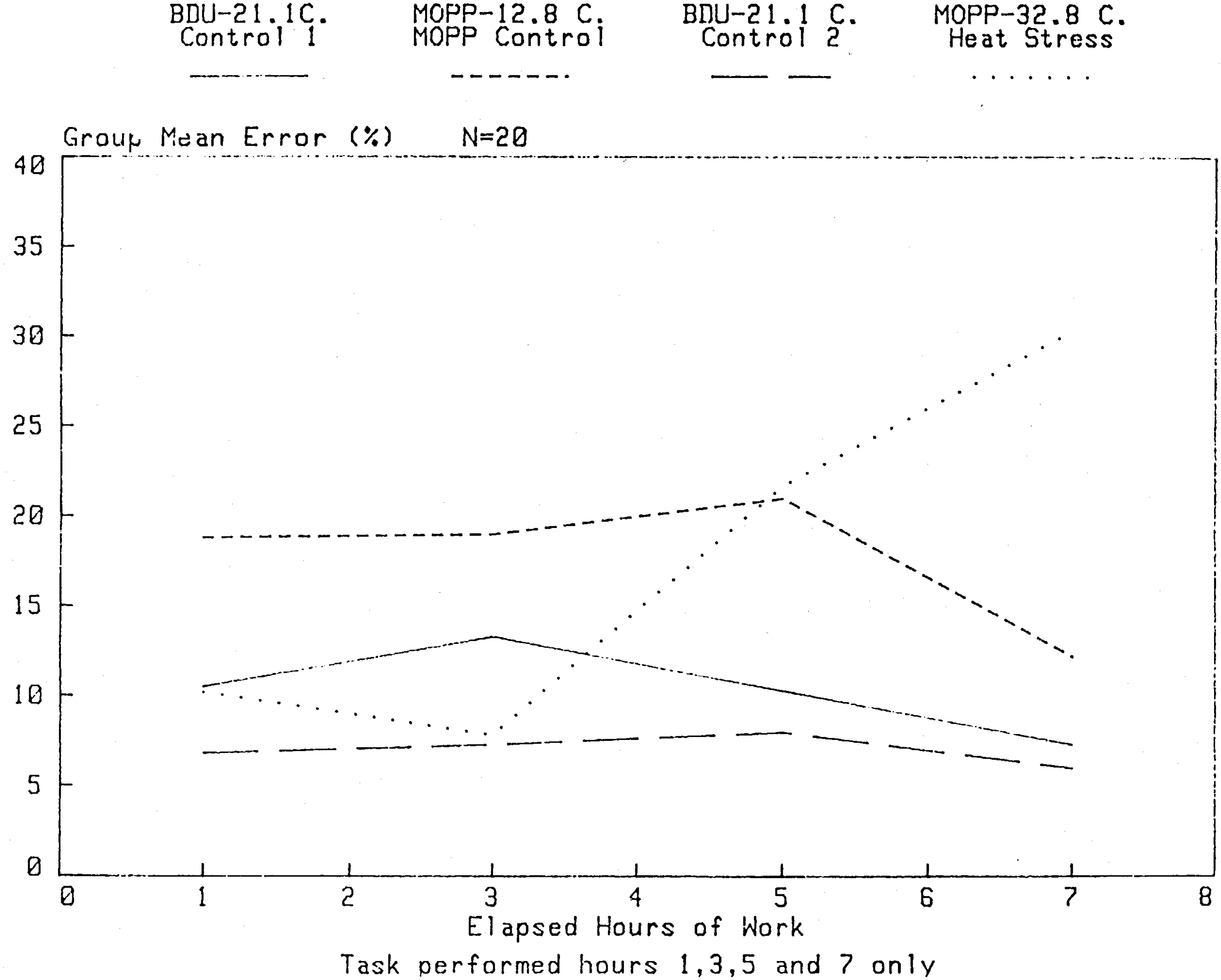
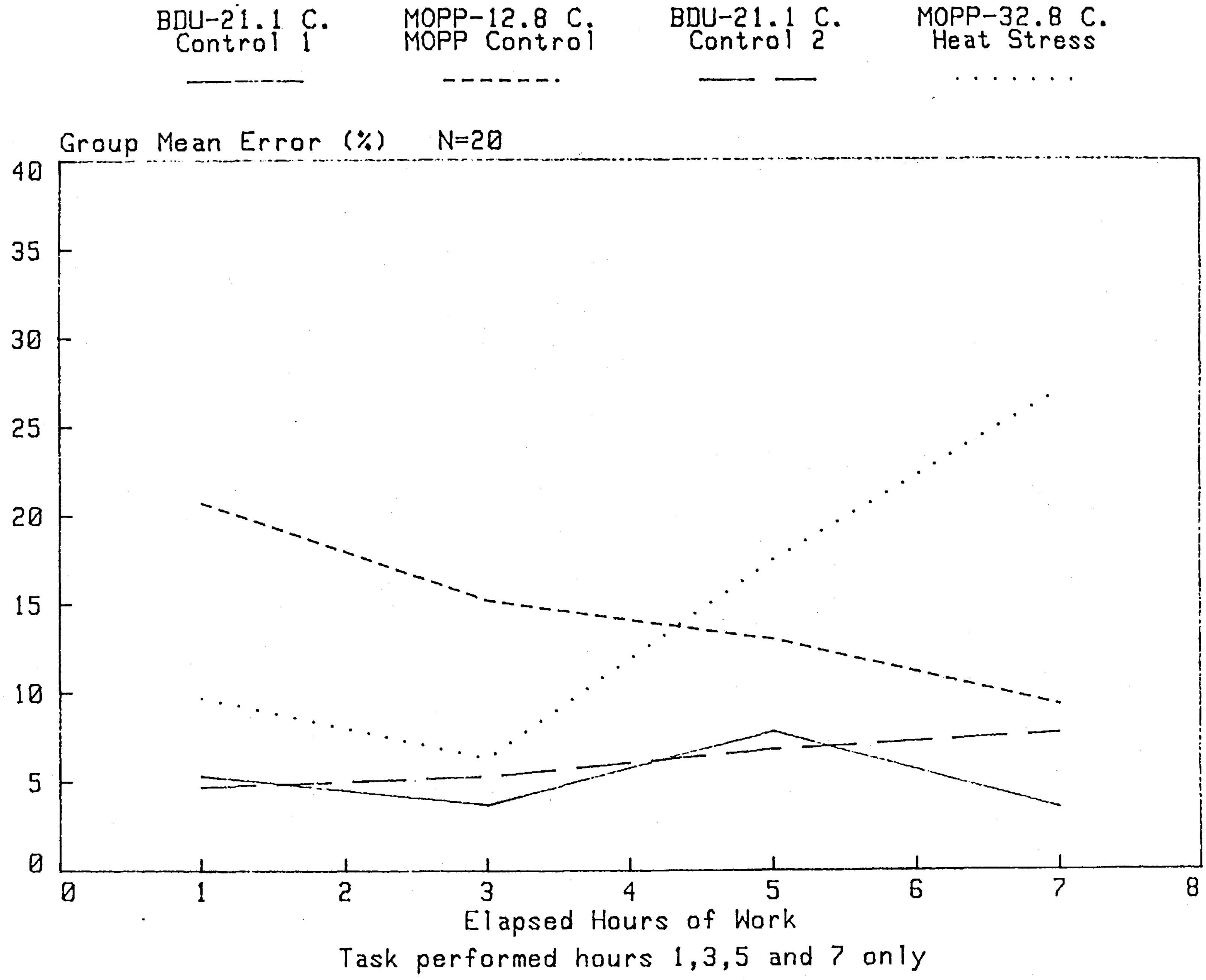
HEAT, MOPP IV & CODEBOOK PERFORMANCE

Total errors (commission + omission)



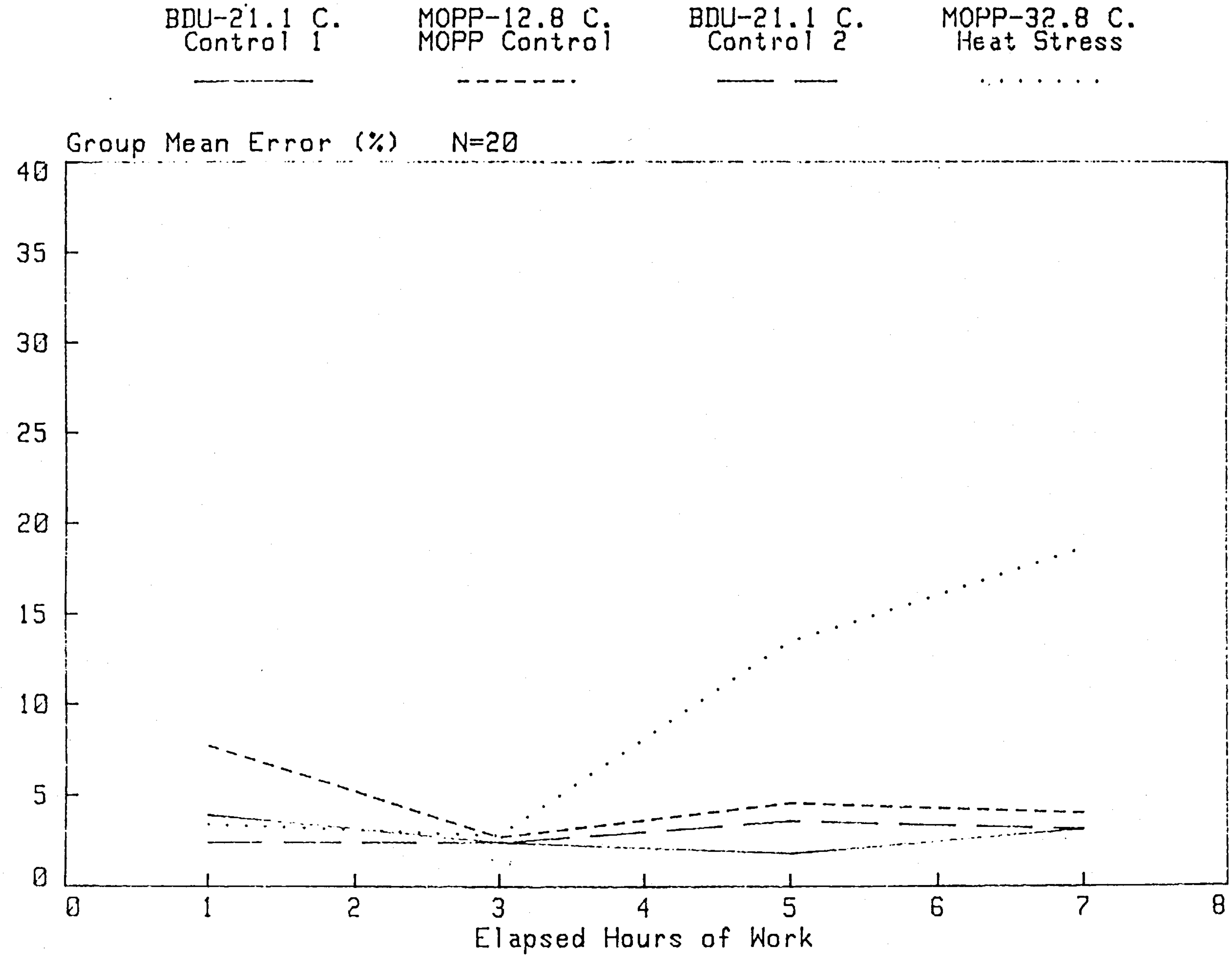
HEAT, MOPP IV & CODEWHEEL PERFORMANCE

Total Errors (commission + omission)



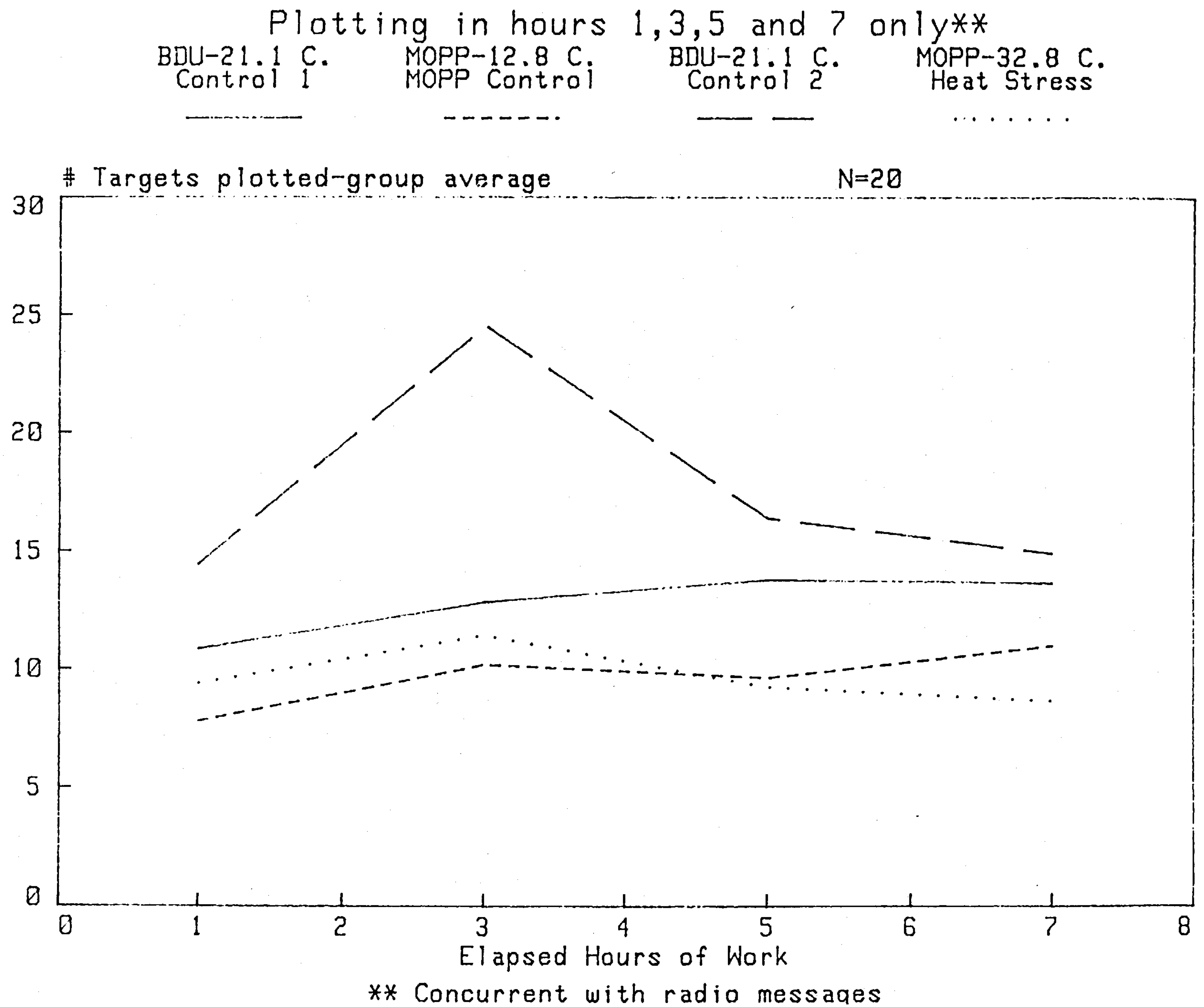
HEAT, MOPP IV & "SITE" COMPUTATION

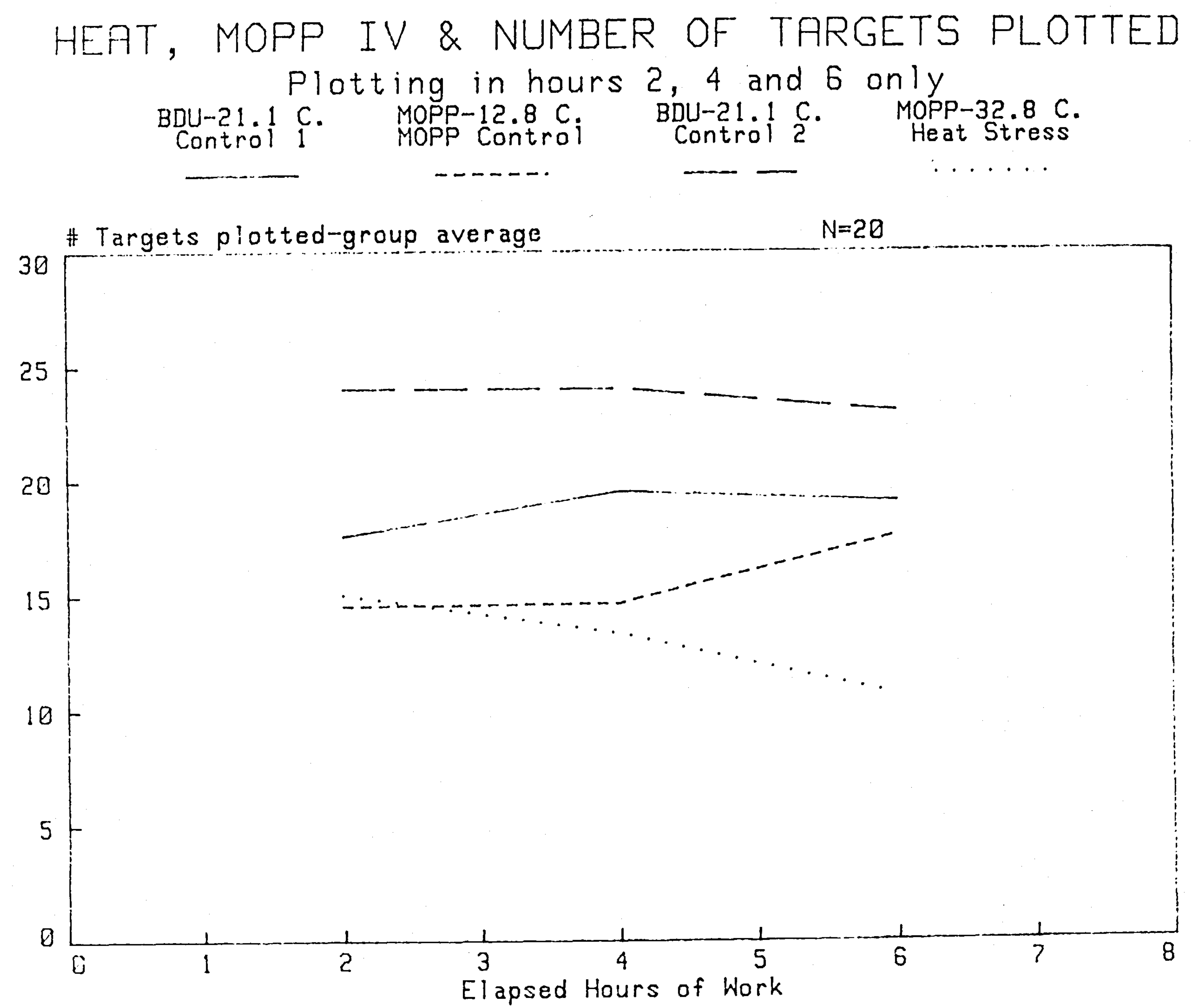
Total Errors (commission + omission)



Task performed hours 1,3,5 and 7 only

HEAT, MOPP IV & NUMBER OF TARGETS PLOTTED




HEAT, MOPP IV & NUMBER OF TARGETS PLOTTED
Plotting in hours 2, 4 and 6 only
BDU-21.1 C. Control 1
MOPP-12.8 C. MOPP Control
BDU-21.1 C. Control 2
MOPP-32.8 C. Heat Stress
# Targets plotted-group average
N=20
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
Elapsed Hours of Work